CLIMATE TRANSPOSITION IN THE GREAT LAKES

PURPOSE. Climate warming will impact Great Lakes water supply components and basin storages of water and heat; these impacts must be understood before secondary impacts can be assessed. Climate variability is of particular concern since it is key for shipping, power production, and resource management. Considerations of situations that may occur (scenarios) help identify possible hydrological effects and bound future conditions. This study serves as the foundation for future U.S.-Canadian studies of socio-economic and environmental resource effects emanating from changes in the hydrological cycle due to climate change.

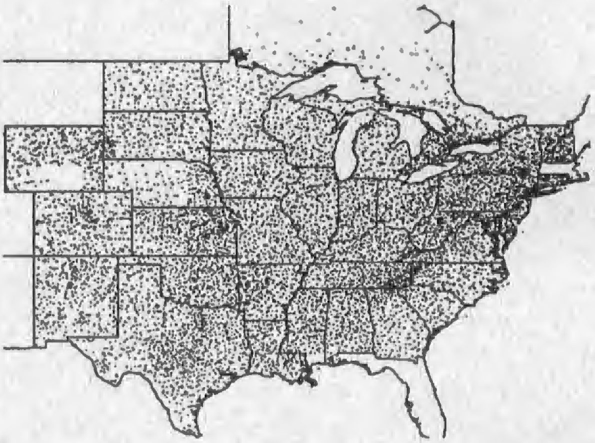
OBJECTIVES.

- Develop climatic scenarios detailed in time & space.
- Match with hydrology model requirements.
- Generate 40-year hydrological time series.
- Assess climate impacts for each Great Lake.

BACKGROUND. Early impact estimates considered simple constant changes in air temperature or precipitation. Then, General Circulation Models (GCMs) of the atmosphere were used to simulate current and double carbon dioxide ($2xCO_2$) climates. Next, researchers used hydrological components of GCMs to estimate hydrology impacts. Subsequently, others began linking regional hydrological models to GCM outputs to assess hydrological impacts. The Environmental Protection Agency coordinated several regional studies. EPA contractors applied monthly adjustments, generated from GCM "present" and $2xCO_2$ simulations, to daily historical data sets to estimate $2xCO_2$ climate scenarios. GLERL then simulated $2xCO_2$ Great Lakes hydrology, lake thermodynamics, and ice cover with their models from these scenarios. The EPA studies, in part, and the high water levels of the late 1980s prompted the International Joint Commission (IJC) to reassess climate change impacts on Great Lakes hydrology and lake thermal structure. GLERL adapted EPA study methodology for the IJC studies to consider $2xCO_2$ GCM scenarios supplied by the Canadian Climate Centre.

GCM LINKAGE PROBLEMS. GCM components, assumptions, and data have inherent large uncertainties. Solar insolation at the top of the atmosphere, and over-water/over-land atmospheric relationships, are assumed unchanged. Spatial and temporal variabilities of the "present" and $2xCO_2$ data sets are the same in both the EPA and IJC studies. The method does not reproduce $2xCO_2$ differences in GCMs but preserves meteorological patterns found in the historical data. The coarse resolution of the GCM grids and the use of monthly adjustments force inappropriately large spatial and temporal scales. Information transfer from GCM grids ignores interdependencies in meteorologic variables.

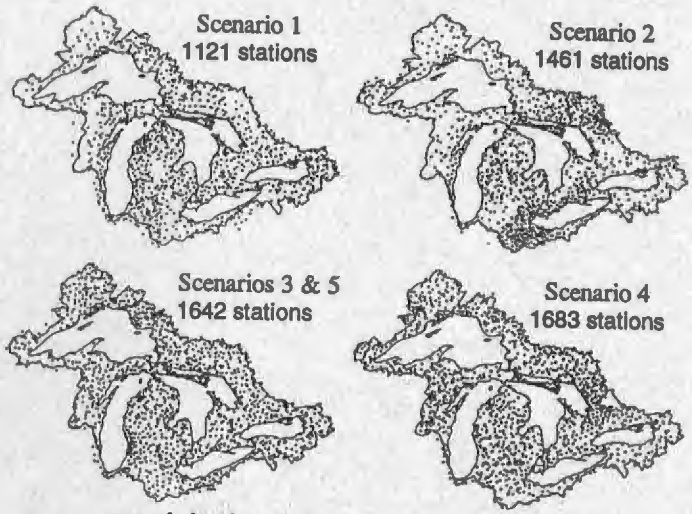
GLERL & THE MIDWEST CLIMATE CENTER. While the EPA and IJC studies looked at changes in mean hydrological values, variability changes were unaddressed. This variability is the singular key problem for shipping, power production, and resource managers. ***GLERL*** and the ***Midwest Climate Center*** (MCC) investigated variability changes with data for climates existing to the south and west of the Great Lakes that resemble some $2xCO_2$ GCM scenarios. ***MCC assembled data sets for 4 climates transposed to the Great Lakes and estimated lake effects to apply to them.*** This preserves reasonable spatial and temporal variations in meteorology and the interdependencies that exist between the various meteorological variables. It also allows the use of appropriate spatial and temporal scales, better matching the models than do GCM output corrections. ***GLERL estimated Great Lakes hydrology for each transposed climate by applying their hydrology models to these data directly and to a base case derived from historical meteorology.***



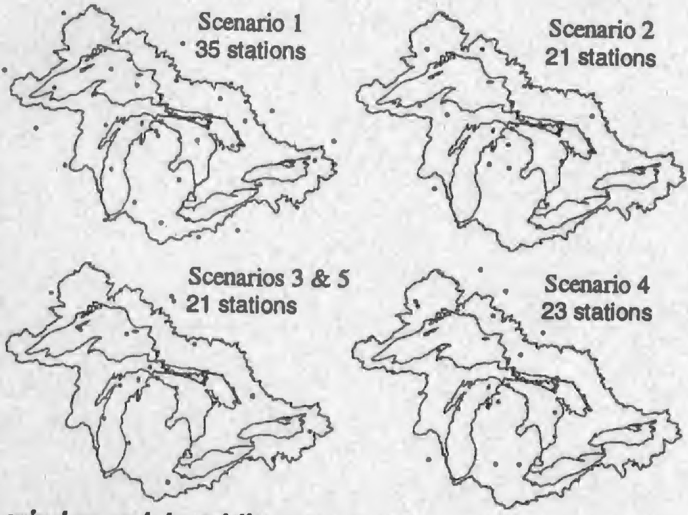
OVER-LAND CLIMATE DATA. Forty three years (1948-1990) of daily maximum and minimum air temperatures, precipitation, and snowfall were obtained for ***13,846*** stations in cooperative observer networks of the ***National Weather Service*** and the ***Canadian Atmospheric Environment Service.*** These give physically coherent spatial and temporal variability for several climates for ***Basin Runoff*** models.

OVER-WATER CLIMATE DATA. Likewise, forty three years (1948-1990) of daily air temperature, wind speed, humidity, and cloud cover were obtained for ***207*** stations from offices of the ***National Weather Service*** and the ***Canadian Atmospheric Environment Service*** and other airport observing stations. These give physically coherent spatial and temporal variability for several climates for use in GLERL's ***Lake Thermodynamics*** models.

PRESENT CLIMATE. The present climate is described by ***1,336*** stations for overland precipitation and minimum and maximum air temperature and by ***42*** stations for over-lake wind speed, humidity, air temperature, and cloud cover. We found all Thiessen weights for each day of 1948-1990 for each of these 7 variables for each of 121 subbasins and 7 lake surfaces. Then we found the weighted spatial average 43-year daily time series for each variable and lake.



precipitation & temperature stations



wind speed, humidity, cloud, & temperature stations

CLIMATE SELECTION. GCM simulations suggest future Great Lakes climates may be similar to present climates to he southwest. We considered four separate climatic regimes corresponding to various GCM temperature and precipitation ranges: ***Scenario 1*** is warm and dry (and is °S and 10°W); ***Scenario 2*** is warm and wet (6°S×0°W); ***Scenario 3*** is very warm and dry (10°S×11°W); and ***Scenario 4*** is very warm and wet (10°S×5°W). We also considered a ***Scenario 5*** which is scenario 3 modified by lake effects.

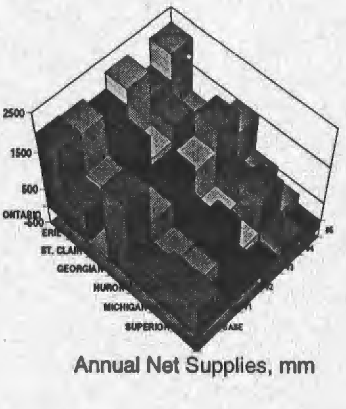
CLIMATE TRANSPOSITION. Station networks were created for each of the 5 scenarios. We repeated data preparation and reduction for all 121 subbasins and 7 lake surfaces for all 7 meteorological variables. These data sets re available at GLERL. GLERL integrated their basin unoff and lake thermodynamics models with overlake precipitation, lake water balances, connecting channel routing ynamics, and lake management policies into a system to estimate lake levels, whole-lake heat storage, and water and energy balances. We applied this system to the historical data, to obtain simulations of ***base case*** hydrology, and to the transposed climates, to obtain simulations for ***scenarios 1*** through *5*.

Average Annual Great Lakes Basin Hydrology Summary

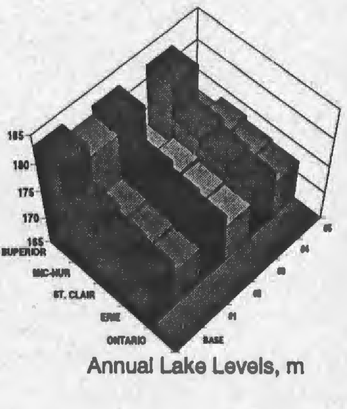
Scenario	Over Land Prec. m^3s^{-1}	Basin Evapo trans. m^3s^{-1}	Basin Run off m^3s^{-1}	Over Lake Prec. m^3s^{-1}	Over Lake Evap. m^3s^{-1}	Net Basin Sup. m^3s^{-1}
Base	13855	7814	6206	6554	4958	7803
6ºS x 10ºW	*+6%*	*+31%*	*-25%*	*+3%*	*+49%*	*-48%*
6ºS x 0ºW	*+24%*	*+43%*	*-1%*	*+25%*	*+33%*	*-1%*
10ºS x 11ºW	*+17%*	*+48%*	*-21%*	*+13%*	*+75%*	*-54%*
10ºS x 5ºW	*+45%*	*+78%*	*+2%*	*+45%*	*+69%*	*-5%*
CCC[a]	-2 %	22 %	-32 %	0 %	32 %	-46 %
GISS[b]	2 %	21 %	-24 %	4 %	27 %	-37 %
GFDL[c]	1 %	19 %	-23 %	0 %	44 %	-51 %
OSU[d]	6 %	19 %	-11 %	6 %	26 %	-23 %

[a]Canadian Climate Centre GCM.
[b]Goddard Institute for Space Studies GCM.
[c]Geophysical Fluid Dynamics Laboratory GCM.
[d]Oregon State University GCM.

HYDROLOGIC SUMMARY. Great Lakes hydrology is expressed as total flows over all lake basins, in the table following, with relative changes from past GCM simulations. Net basin supplies to the Great Lakes drop about one half under the western-most scenarios (1 & 3), resulting from increased evaporation and evapotranspiration. Precipitation increases for the eastern-most scenarios (2 & 4) compensate evaporation/evapotranspiration; net supplies are close to base.



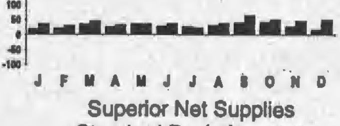
Annual Net Supplies, mm



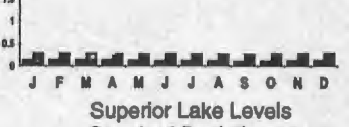
Annual Lake Levels, m

Superior Net Supplies
Average, mm

Superior Lake Levels
Average, m



Superior Net Supplies
Standard Deviation, mm



Superior Lake Levels
Standard Deviation, m